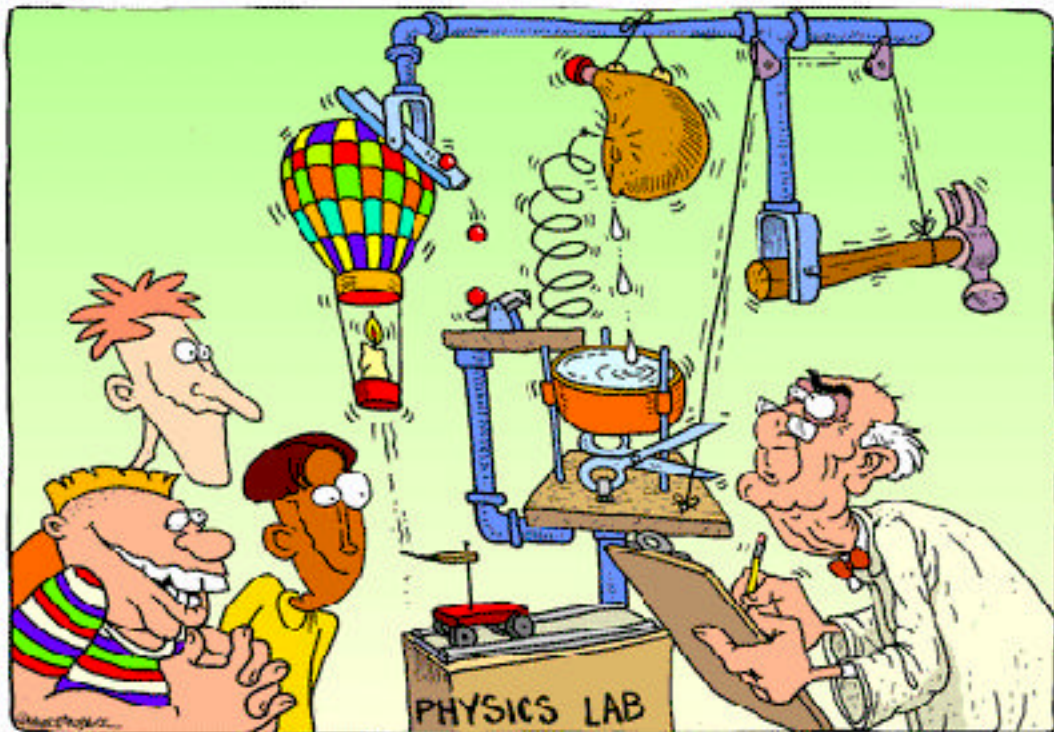


# ***Microwave Measurement Labs***



## **Introduction to the Spectrum Analyzer Lab**

This lab will focus on the basic operation of a microwave spectrum analyzer. The spectrum analyzer is capable of measuring the amplitude and frequency characteristics of repetitive signals over a large dynamic range. As such, the spectrum analyzer is very useful in diagnosing signals from circular accelerators where the repetitive signals are generated from circulating beam.

### **INITIAL SETUP**

This portion of the lab will teach the student about the basic operational functions of the spectrum analyzer (SA), i.e. Center Frequency (CF), Span, Resolution Bandwidth (RBW), Video Bandwidth (VBW), Sweep Time (SWP), and Markers.

1. Turn power on or press the green instrument preset button if the unit is on. (The Spectrum Analyzer (SA) will go through a self-calibration on initial turn on.)
2. Note that the display shows frequencies over the full range of the SA. The noise floor is dependent on frequency; hence, the appearance of stair steps in the response.
3. Hook the calibration test signal located on the bottom of the front panel to the SA input.
4. Punch in the center frequency listed and set the Span to 100 MHz.
5. Note the values of RBW, VBW, and SWP from the screen. Turn on the markers via peak search and note the amplitude value of the signal.
6. Continue to zoom in by pressing the span button and the down arrow. Note what happens to the signal. (If it moves from the center of the screen, press the peak search button, then the marker to center "soft key" on the display.)
7. When a span of 50 KHz has been reached, note the value of RBW, VBW and SWP and peak amplitude. Except for the peak of the signal, the other parameters have changed from the original measurement because they are coupled functions. The analyzer automatically changes them to give the best display while remaining calibrated.
8. Under the trace menu, press trace B, clear write B, then view B after the sweep.
9. Press clear write A. This will allow for comparison of signals in the next two steps.
10. The RBW, VBW, and SWP can be controlled manually. Decrease the sweep time manually to 100 msec. The SA will display a message indicating un-calibrated sweep. Sketch the results. What has happened to the amplitude and frequency display of the signal?
11. Leave the sweep in manual mode and decrease the RBW manually. Sketch the results. What happens to the signal?

### *Signal measurements*

This portion of the experiment will measure a variety of signals utilizing an arbitrary waveform generator. Signals will be checked on an oscilloscope before viewing them on the SA. **IT IS IMPORTANT THAT ZERO VOLTS DC IS PRESENTED TO THE SA INPUT. DC VOLTAGES WILL DESTROY THE FRONT END CIRCUITY!!!**

12. Press the Instrument preset button. Turn on the oscilloscope.
13. Turn on the function generator and set it to deliver a sine wave at 1 MHz, with 50 mVolts RMS amplitude. **Check to see that there is Zero volts of offset on the oscilloscope!** The scope should have a 50-ohm termination on its input.
14. Set the SA for a Start Frequency of zero Hz and a Stop Frequency of 20 MHz.
15. Plug the function generator output into the SA input.
16. Reduce the VBW to reduce the displayed noise floor. Under the Peak Search menu, select more, then Peak Threshld. Set the threshold to be above the noise floor.
17. Use the Peak Search and Next Peak Right functions to gather data for a plot. Sketch the display. Does the amplitude and harmonic content agree with the function generator and Fourier theory?
18. Set the SA to a CF of 1 MHz. Reduce the Span to 100 KHz; adjust VBW to reduce displayed noise.
19. Using Peak Search and Delta markers, find the peak to close in noise ratio of the signal. Sketch the display.
20. The function generator works by converting digital bits to an analog signal. How many bits do you think are used in the generator? (Remember that the 50 mVolt signal is well below the maximum output for the generator.)
21. Repeat steps 12 through 20 for a Square Wave, Triangle, and Pulse waveforms.

### *Noise Measurements*

While the SA has a very high dynamic range, it is still limited by noise. This part of the experiment will measure the noise performance of the SA.

22. Press Instrument Preset.
23. Attach a 50-ohm load to the input of the SA.
24. Set the RBW to 1 MHz and adjust the VBW to 1 KHz to reduce the viewed noise. The VBW will render the average noise floor value for the SA. Using the markers, sketch the noise display data.
25. Note that the attenuator is automatically set to 10 dB. This is the input attenuator that sets the dynamic range of the measurement. The attenuator also degrades the noise performance of the SA. Manually set the Atten to 0 dB under the Amplitude menu. (This removes all attenuators and makes the front-end electronics more vulnerable to overload signals.)
26. Repeat step 24.

27. Calculate the noise floor as a function of frequency in a one Hz bandwidth. (The ratio of 1 MHz to 1 Hz is a factor of 60 dB.) How does this value compare to the ambient noise floor at 290 Kelvin? ( $kTB = -174$  dBm/Hz)

### *Modulation Measurements*

This section of the experiment will explore the zero span mode of SA operation. In zero span, the SA is a fixed tuned receiver. The SA also contains a built in AM/FM demodulator that will be used to listen to local radio stations.

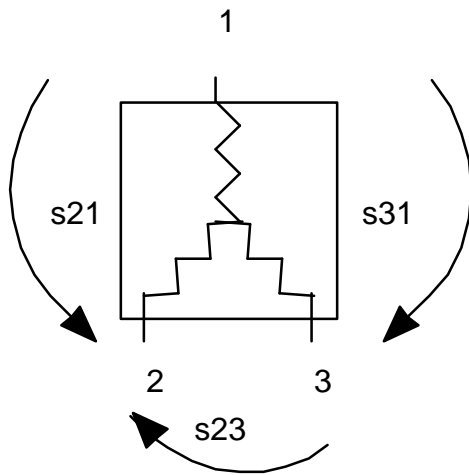
28. Press Instrument Preset.
29. Hook up the wire via alligator to BNC adapter to the SA. This will serve as a crude antenna.
30. FM stations are located between 88 and 108 MHz. Set the SA as follows: CF= 98 MHz, Span= 20 MHz, Atten=0 dB.
31. Using the peak search function, find the strongest station. Use MKR to CF to center the station. (Note that the FCC allocates FM stations at 200 KHz intervals with the following locations: 88.1, 88.3, 88.5...MHz)
32. Zoom in on the signal with the Span and Down arrow to 500 KHz Span.
33. Note the RBW, VBW, and SWP. Sketch the display. How wide is the frequency deviation?
34. Set the Span to 0 Hz. This puts the SA in fixed tuned receiver mode.
35. Under the Auxiliary control menu, select AM/FM demod and turn on FM demod.
36. Turn up the volume knob on the front panel. What do you hear?
37. The choppy sound is because demodulation only occurs during the sweep. Decrease the SWP manually until the choppiness disappears. Hear anything?
38. The RBW is less than the deviation measured earlier. Increase RBW manually until the signal is intelligible. Note where the RBW is optimum.
39. Try the same experiment with a weaker station. Can you detect degraded performance if the RBW is too wide?
40. If time permits, make the same measurements for the AM band, 550 to 1600 KHz. Channel spacing in the AM band is 10 KHz, with 550, 560, 570...KHz designations.

This is a typical use for a SA in a circular accelerator, except the signals listened to are those generated from the beam going through a pickup device. The FM case is analogous to longitudinal dynamics such as synchrotron oscillations. The AM case can be use for betatron tune or emittance monitoring.

## Microwave Components Measurements Lab

All components in this lab operate with a nominal 1-2 GHz bandwidth. Start with a full two port calibration over the frequency range of 0.5-2.5 GHz. Use 401 points and split screen, i.e. magnitude on channel 1 and phase on channel 2. (Set the analyzer to split screen under display menu.) Some of the measurements are full vector, others magnitude only. NOTE that all unused ports should be terminated in 50 ohms for all measurements.

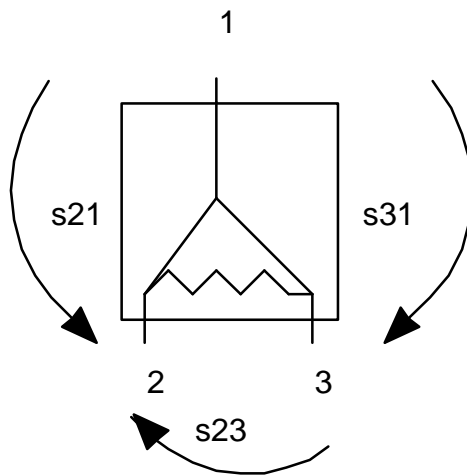
### *Resistive Power Splitter*



Make a vector measurement, i.e. magnitude and phase, of  $s_{21}$  and  $s_{31}$ . Adjust the electrical delay for channel 2 under the scale menu until the phase is flat. Use the same electrical delay for both measurements. Sketch the amplitude and phase of each measurement. What is the amplitude and phase balance? What is the group delay of the device?

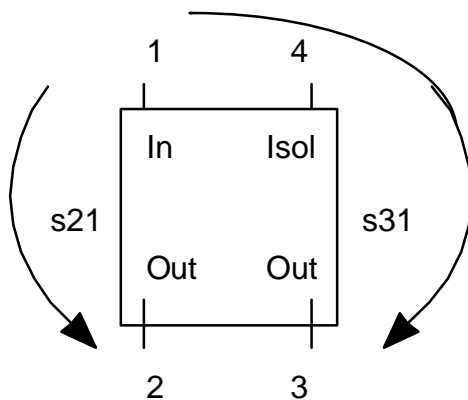
Measure  $s_{23}$  magnitude transfer function. Sketch the result. What is the isolation between the two output ports?

### *Wilkinson Power Splitter*



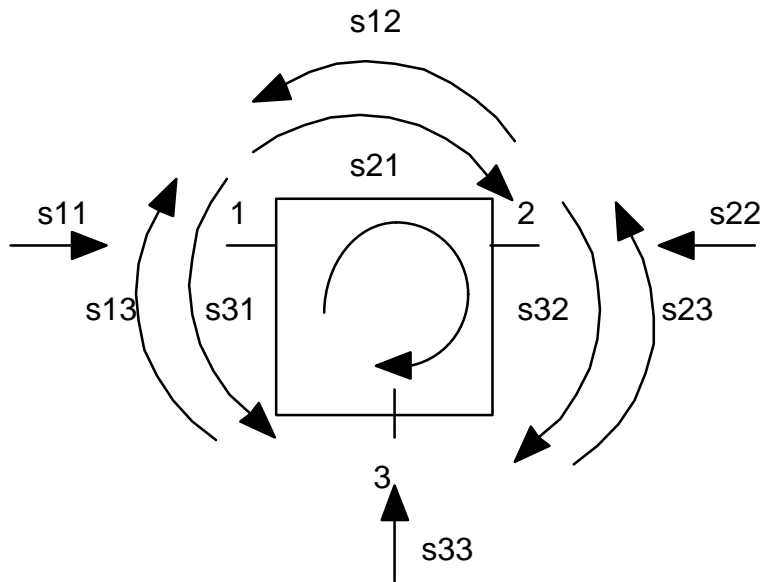
Repeat the measurements for the resistive splitter described above. Compare and describe the difference between the two splitter types.

### *180 degree Hybrid*



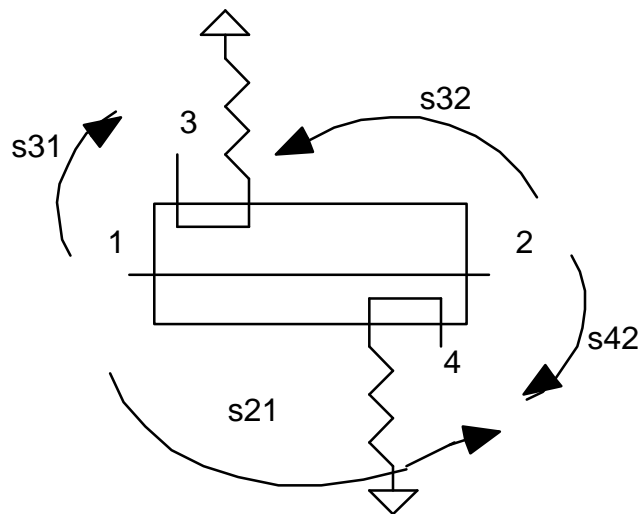
The 180-degree Hybrid is a four port device. Make a vector measurement, i.e. magnitude and phase, of  $s_{21}$  and  $s_{31}$ . Adjust the electrical delay as before for the phase signal until the phase is flat. Use the same delay value for both  $s_{21}$  and  $s_{31}$ . Sketch the amplitude and phase of each measurement. What is the amplitude and phase balance?

### Circulator



The circulator is a three port device. This measurement will only use the magnitude function of all nine s parameters. Measure the s parameters as shown in the diagram. Use channel 1 for  $s_{11}$ ,  $s_{22}$ ,  $s_{33}$  and channel 2 for the other six parameters,  $s_{21}$ ,  $s_{12}$ ,  $s_{23}$ ,  $s_{32}$ ,  $s_{13}$ ,  $s_{31}$ . Sketch the results and list rough magnitude values in the form of a 3X3 s matrix. From inspection of the parameters, describe the signal flow through the device.

### Dual Directional Coupler



Measure the magnitude transfer function parameters  $s_{31}$  and  $s_{42}$ . This is called the coupling factor. Sketch the results and state the average coupling factor for the device. What is the coupling bandwidth of the device, i.e. 3 dB below the coupling value?

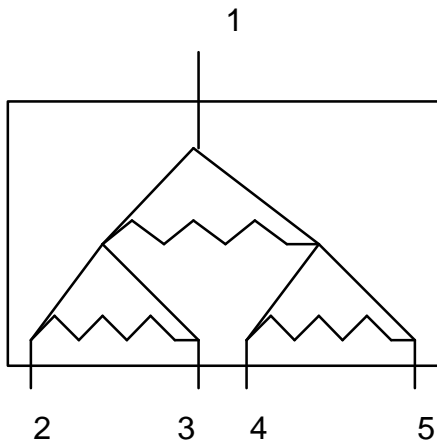
Measure the magnitude transfer functions  $s_{32}$ . Sketch the results. The ratio of  $s_{31}/s_{32}$  is a measurement of directivity. State the average value of directivity for the bandwidth measured above.

Measure  $s_{12}$  or  $s_{21}$  magnitude. This is the insertion loss of the device. State the average insertion loss.

What can you say about the quality of this directional coupler?

### EXTRA CREDIT

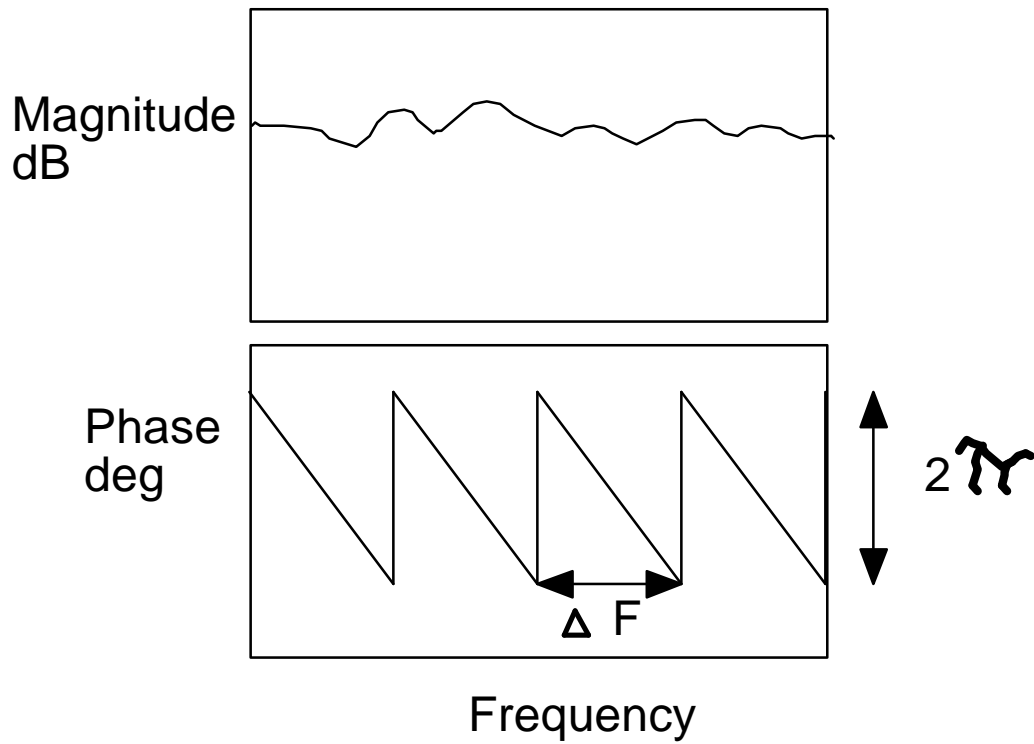
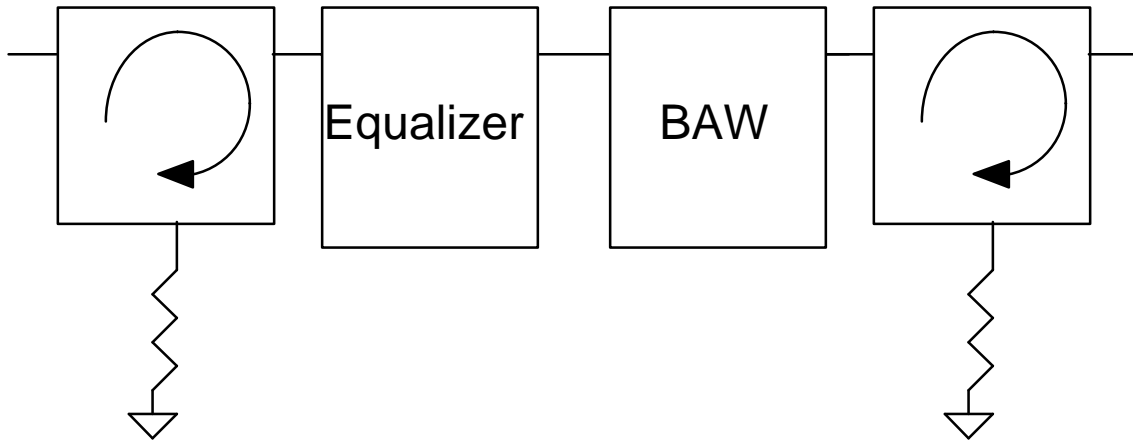
*Four way Wilkinson splitter*



Repeat the Wilkinson splitter experiment with the 4 way Wilkinson splitter. Pay special attention to the isolation measurements between  $s_{21}$ ,  $s_{31}$  and  $s_{41}$ ,  $s_{51}$ .



*Bulk Acoustic Wave (BAW) delay.*



$$\text{Group Delay} = t_d$$

$$t_d = d\phi/d\omega = 2\pi / 2\pi \Delta F$$

The BAW utilizes a sapphire crystal as a transmission medium. An acoustic wave is launched through the crystal that travels at the speed of sound in the crystal, about one microsecond per centimeter. The launch onto the crystal has a very high impedance, hence very poor match to 50 ohms. (This should give you a hint about the use of circulators.) BAW delays are used to create long delays with minimal dispersion in a small package.

This experiment will be done without calibrating the analyzer. Measure both amplitude and phase of  $s_{21}$ . Again use magnitude on channel 1 and phase on channel 2. Start the first measurement with a center frequency of 1.5 GHz and a span of 2 MHz. IMPORTANT, set the sweep time to 10 seconds. Sketch the magnitude and phase of  $s_{21}$ . (Electrical delay should be set to zero seconds.) Using two markers, calculate the group delay, i.e.  $\Delta \text{phase} / \Delta \omega$ . Enter this delay value in the electrical delay under the scale menu for the phase on channel 2. Fine adjust the electrical delay until the phase is flat.

Increase the span to 10 MHz and readjust the electrical delay until it is flat. Repeat for 100 MHz, 500 MHz and 2000 MHz. For a span of 2000 MHz (2 GHz) sketch both magnitude and phase. What is the 3 dB bandwidth of the device? What is the average insertion loss? What is the group delay?

Store both channel displays in memory under the display menu, Data into memory, then Data and Memory. Next start reducing the sweep time using the arrow buttons. At what value of sweep time does the displayed response change? Remember that group delay is defined as the rate of change of phase with frequency. Calculate the rate of change of phase over the frequency range with the above measured group delay. With very long electrical delays, the rate of change of phase with frequency sweep is so rapid that the phase lock loops in the analyzer are unable to maintain phase lock, hence the displayed signal begins to degrade.

## System Noise Figure Measurement Lab

In this lab, Noise Figure of an amplifier system will be measured as a function of Frequency. The measurements include network analyzer measurements of active and passive devices.

The amplifier to be measured has a 1-2 GHz bandwidth. Set up the network analyzer as follows:

1. Set Start Freq. To 0.5 GHz, Stop Freq. To 2.5 GHz
2. Single channel amplitude measurement
3. Choose Cal Menu, Cal Response, Connect through
4. Verify that the cal is correct, i.e. 0.00 dB transmission response.
5. Insert and measure the 3-dB pad. Note and sketch the transfer function
6. Insert and measure the two 20 dB pads. Note and sketch the transfer function.
7. Hook up the amplifier as in figure 1 below with the two 20 dB pads on the INPUT.
8. Why is it important to have the pads on the input of the Amp?
9. Turn the amplifier on with the +15 Volt power supply. CHECK POLARITY!
10. Note and sketch the amplifier transfer function. The actual gain is the network analyzer value plus the value measured for the two 20 dB pads.

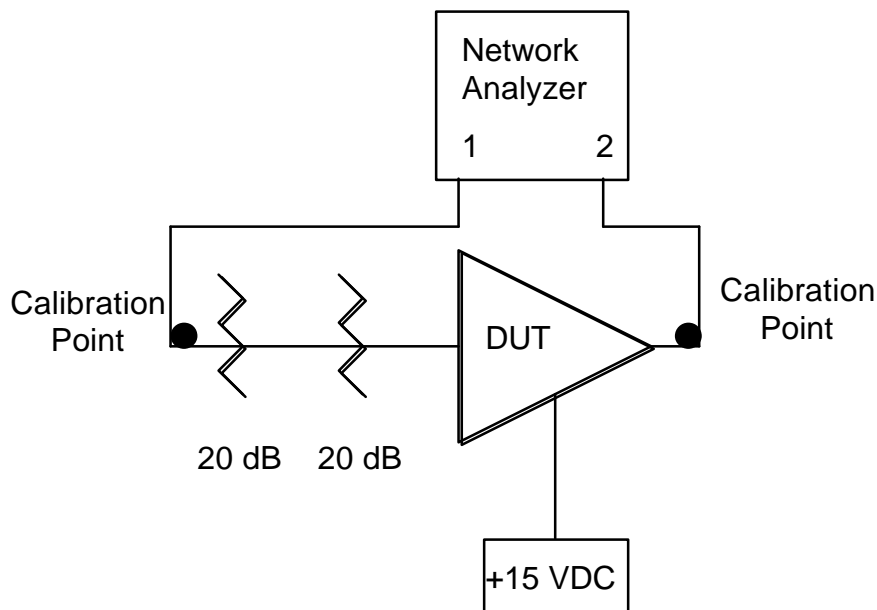


Figure 1

11. Prepare to make the noise figure measurements by setting up the Spectrum analyzer as follows:
12. Instrument preset, Center Freq. 1.5 GHz, Span 100 KHz, RBW 30 KHz, VBW 3 Hz, Log scale 2 dB/Div. Attenuator 0 dB.
13. Hook up the amplifier and noise source as shown at the top of Figure 2 below.
14. With the amp turned on and noise source off, adjust the reference level to get a trace near the bottom of the screen. Allow the amplifier to warm up for a few minutes.
15. Under the trace menu, “write” then “view” trace A after the sweep.
16. Turn on the noise source (+28 Volts, CHECK POLARITY!), “write” then “view” trace B after the sweep.
17. Turn on delta markers under marker menu
18. Under trace menu, find A exch B and read delta marker value for “Y Factor”.
19. Compute the Noise Figure with the measured Y factor and the value of the Excess Noise Ratio (ENR) for T2, printed on the noise source.
20. Repeat the measurement at several other frequencies across the pass band of the amplifier. Plot your results.
21. Repeat the measurement of noise figure at 1.5 GHz with the 3 dB attenuator at the output of the amp.
22. Repeat the measurement of noise figure at 1.5 GHz with the 3 dB attenuator at the input of the amp. Compare to the calculated “system” noise performance using the formula for the series of individual devices.
23. The 3 dB attenuator can represent other system components such as an antenna cable or other lossy device. What can you say about location of devices for optimum noise performance?

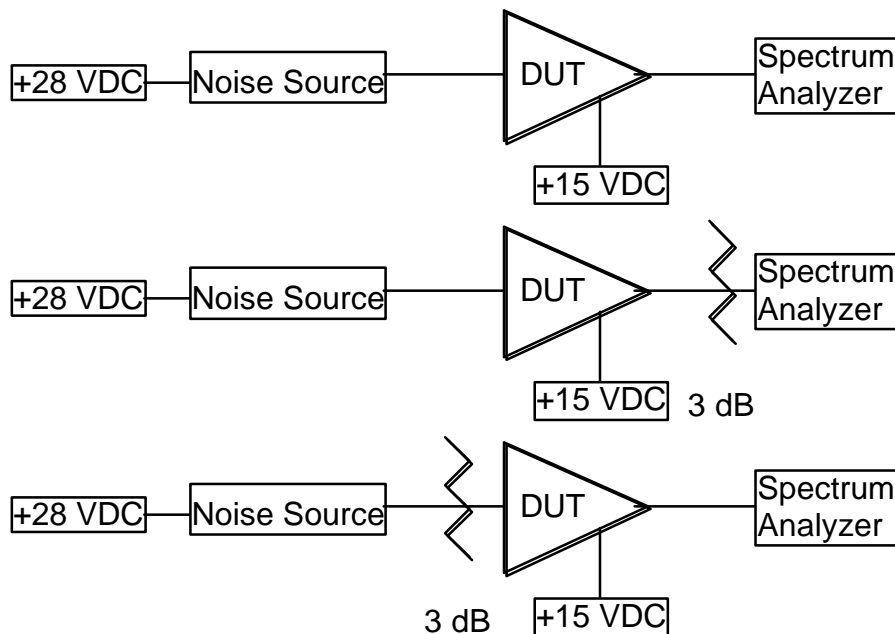


Figure 2

## **TDR Measurement Lab**

In this lab, you will measure a number of devices with a Time Domain Reflectometer (TDR). The TDR is a delicate instrument and should be handled with care. Static discharges can easily ruin the sampling head, so be sure to discharge yourself to ground before touching the unit.

### **INITIAL SETUP**

1. Turn power on, both back panel and front panel switches must be toggled.
2. Push the setup button on the TDR plug in. Select the 18 GHz option.
3. Under the marker menu on the main frame, select markers on. Explore some of the other marker features before continuing. They may make your measurements easier.
4. Push the TDR/TDT setup button on the plug in and press TDR preset.
5. Hook up the SMA test cable. Observe what happens to the display.
6. Make the following adjustments to the set up: Time base 2 ns per division, horizontal offset to put the open end of the cable in the left half of the display; Channel 1 Vertical 50 mVolts per division and offset set to make 50 ohms in the middle of the screen.
7. Under the TDR/TDT setup menu press normalize response, then establish reference plane. Follow the instructions on the screen for the short and load calibrations. At this point, your marker should read out in ohms for the vertical scale and time for the horizontal scale. Is the marker close to zero picoseconds at the open end of the cable?

### ***8. Connector Measurements***

9. RF and Microwave systems rely on a number of different connection standards. This part of the lab will allow you to evaluate the quality of each type.
10. Adjust the vertical sensitivity to 20 mVolts per division, the time base to 200 ps per division.
11. Reconnect the SMA 50-ohm termination. Sketch the displayed response. Use the marker to document impedance variations as a function of time.
12. Connect a Type N load with the use of the appropriate SMA to N adapter. Sketch the displayed response.
13. Insert a type N elbow between the adapter and load, Sketch the response.
14. Repeat measurements 11 and 12 for the TNC, BNC, and Lemo connections. (No TNC loads are available, hence transition back to type N.)
15. What can you say about each connector family? How do you rank the connectors in order of best to worst performance?

## *16. Transmission Line Measurements*

17. The TDR is especially useful in measuring transmission lines. Coaxial and microstrip lines will be examined.
18. Attach the SMA to N adapter to the test cable and note the time at the open circuit with the marker.
19. Hook up the microstrip line, leaving the other connector open. Using the marker, measure the electrical length. Using a ruler, measure the mechanical length. What is the velocity of propagation of the microstrip? Times measured are two way travel. Remember to subtract the length of the adapter.
20. Terminate the microstrip with a 50-ohm N termination.
21. Under the acquisition menu, turn off averaging.
22. Run your finger along the transmission line. What do you observe? Can you see where the 90-degree bend is in the line? How well is it matched?
23. Adjust the vertical sensitivity to 100 mVolts per division and remove the stripline.
24. Hook up the RG 62 cable with a 50-ohm termination on the other end.
25. What is the velocity of propagation and impedance of this cable?
26. Change the time base to 2 ns per division and remove the 50-ohm termination.
27. Sketch the display. How can the reflection coefficient be greater than one? Explain what is going on.

## *28. Complex Loads*

29. The TDR can also be used to interpret complex impedances.
30. Four circuits labeled 1 through 4 are incorporated into the blue boxes with the BNC connectors. With the appropriate adapter, measure each of the circuits.
31. Sketch the display, list the topology, and component values for each circuit